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An Assessment of the Properties of Internal Combustion Engine Lubricants Using an Onboard Sensor

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Outline

- Goal and motivation
- Background
- Research objectives
- Research methodology
  - Bench-top experiments
  - Engine experiments
- Conclusions

Goal and Motivation

- Monitor lubricant degradation in internal combustion engines through direct, in-situ measurement of lubricant properties

- Benefits
  - Cost and energy usage
    - Lubrication improvements may save up to 20% of the total annual energy consumed by vehicles in the US (~14 billion US dollars)
  - Logistics
    - Tailor oil change intervals to actual vehicle needs
  - Environmental

Background

- Current Methods
  - Algorithms based on driver inputs or supplemented with oil property measurements (e.g., dielectric constant)

Property	Condemning Limits
Viscosity @ 100°C	10-18 cSt From +25% to -18% ± viscositygrade from new oil
TBN	0.5-4 mg KOH/g -50%
Dielectric Constant	0.01 0.2

- Disadvantages
  - Contamination might be overlooked
  - Over or underestimation of oil change interval

- Needs and Challenges
  - Measure oil properties accurately, directly and in-situ
  - Validate threshold values indicative of oil degradation
  - Identify potential causes of measured lubricant condition

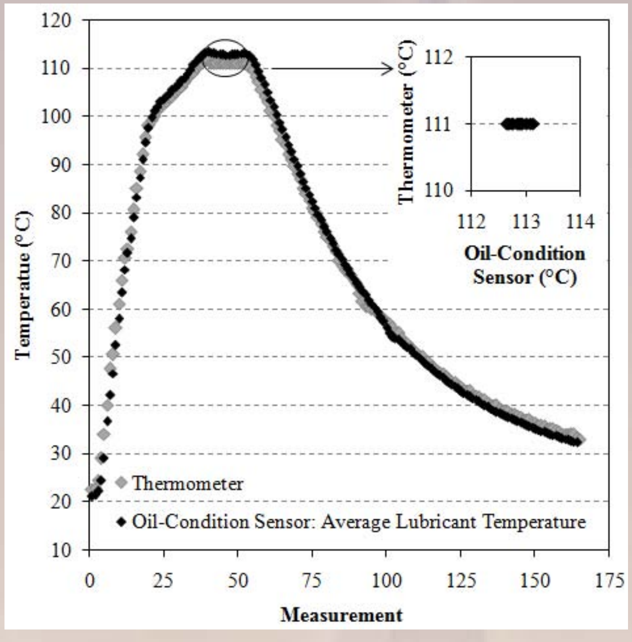
Research Objectives

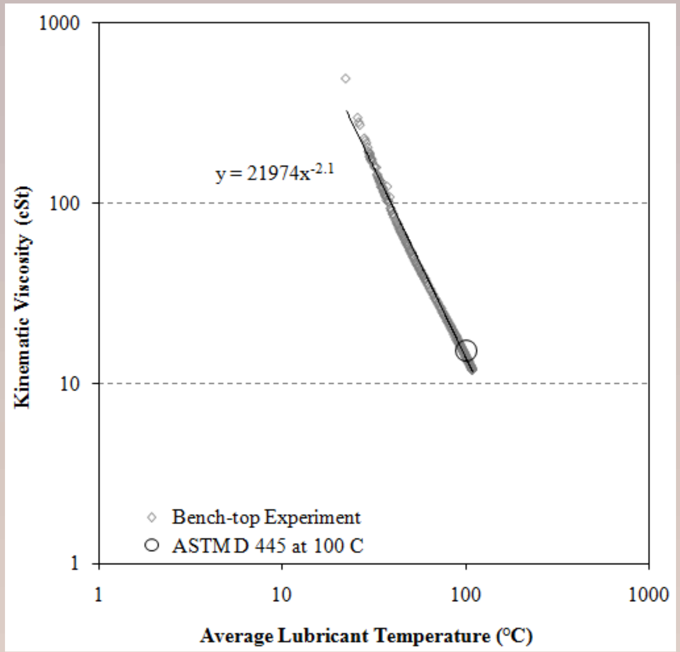
- Quantify the accuracy and precision of lubricant property measurements from an on-board oil-condition sensor
- Correlate changes in the physical properties of the lubricant with likely causes of oil degradation
- Quantify changes in the physical properties of the lubricant with respect to engine operating time

Research Methodology

- Properties measured by the sensor
  - Temperature (55°C to 150°C)
  - Density (0 to 1.5 g/cm3)
  - Viscosity (0 to >50 cP)
  - Dielectric Constant (1.00 to 6.00)
- Lubricant type
  - Rotella T 15W-40
- Bench-top experiments
  - Quantify accuracy of sensor output
  - ASTM standards or reference instruments
- Engine experiments
  - Monitor properties changes with respect to engine operating time

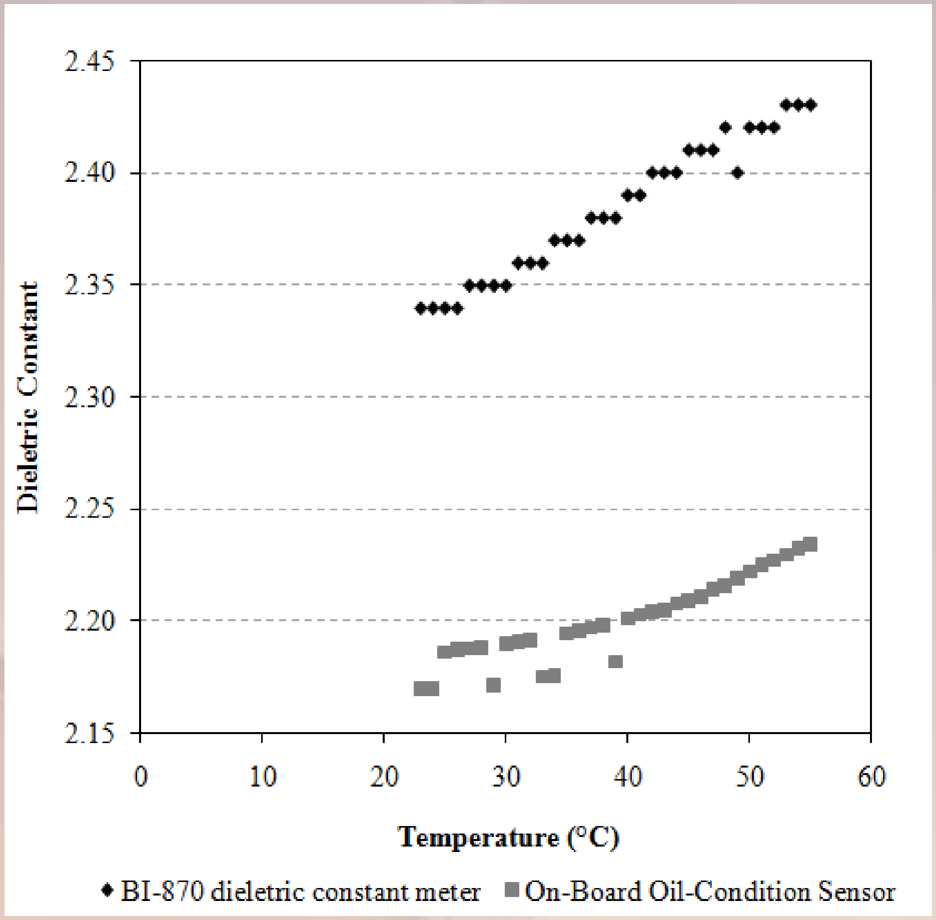
Results from Bench–Top Experiments: Temperature and Density





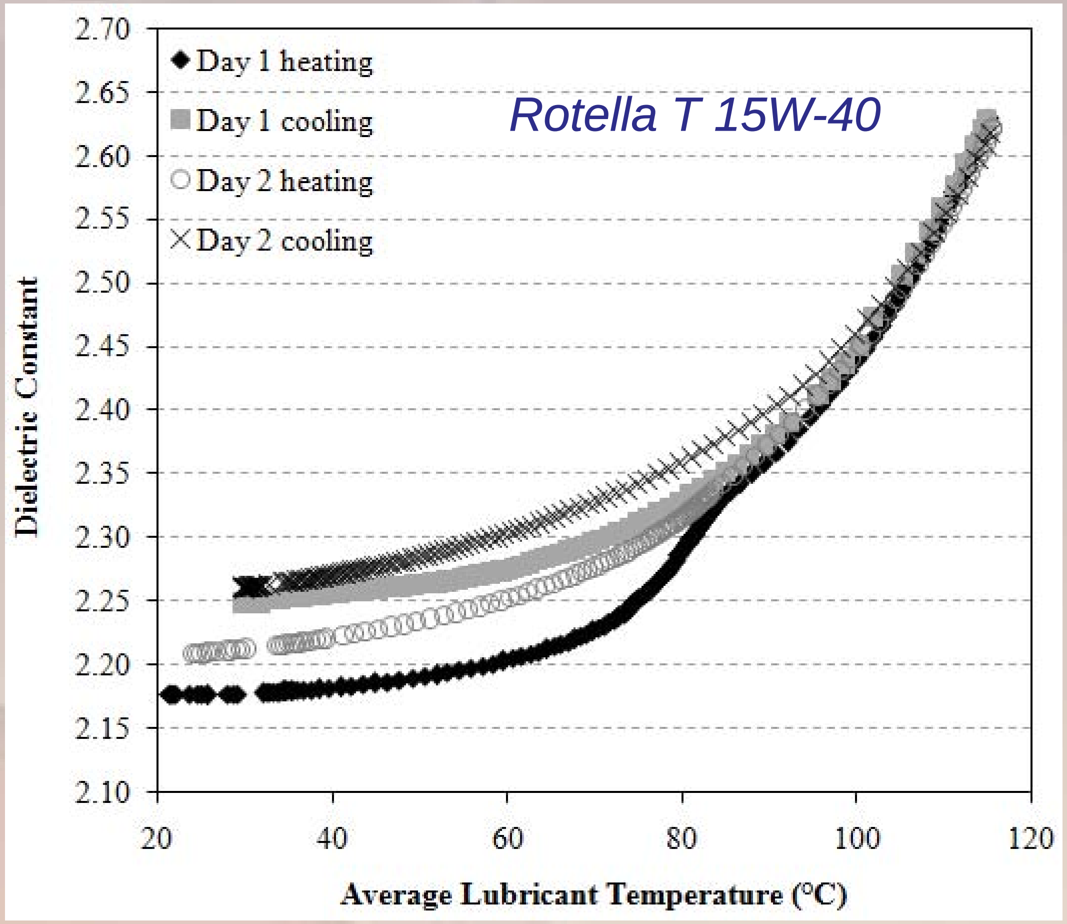
- Sensor requires ~20 min to reach thermal equilibrium
- Agreement with reference reading to within 2°C
- Viscosity measurements conducted with the sensor are within 6% of ASTM D445 values

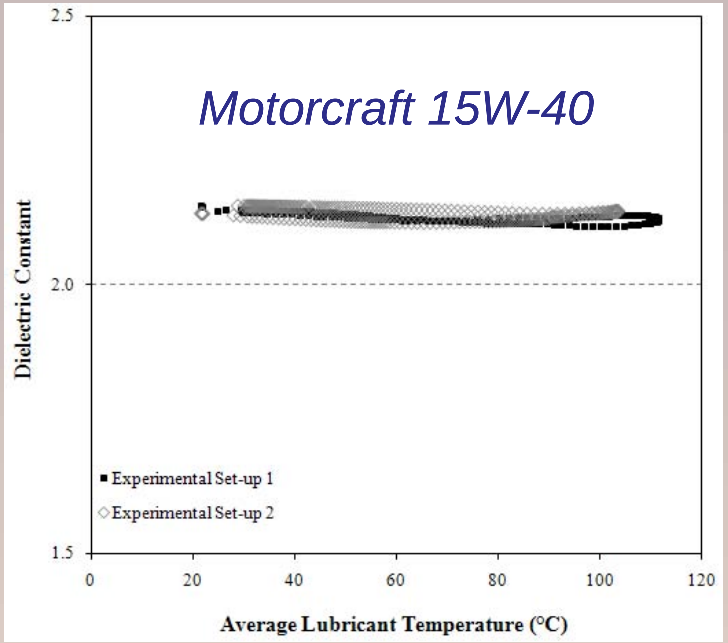
Results: Dielectric Constant



- Sensor output compared to a reference instrument (Brookhaven's BI-870 dielectric constant meter)
- Accuracy of the reference instrument validated a priori
- Sensor reading ~ 6.5% less than reference instrument

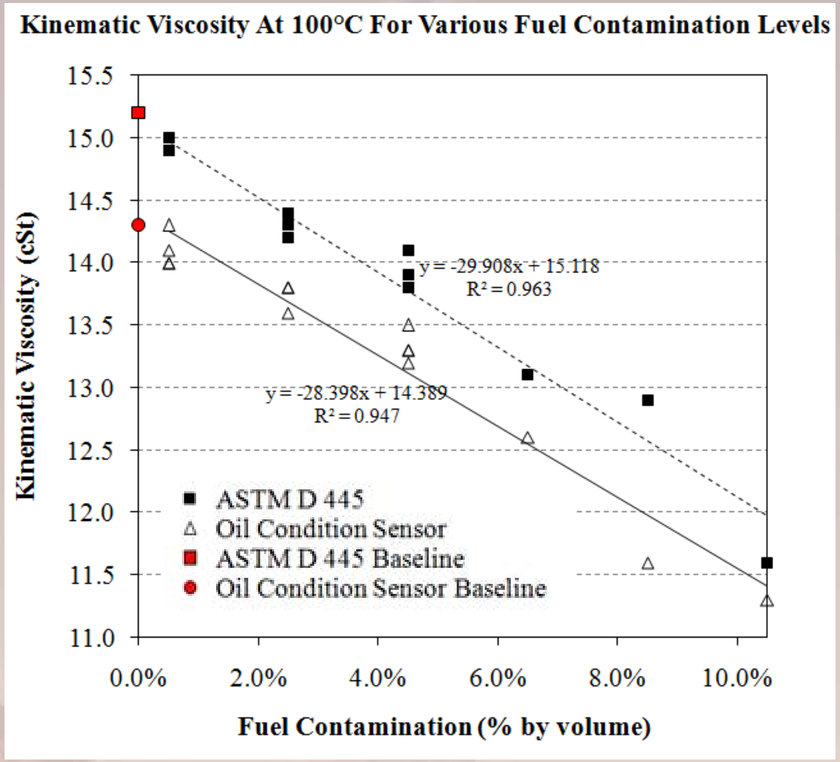
Dielectric Constant: Thermal Cycle Results

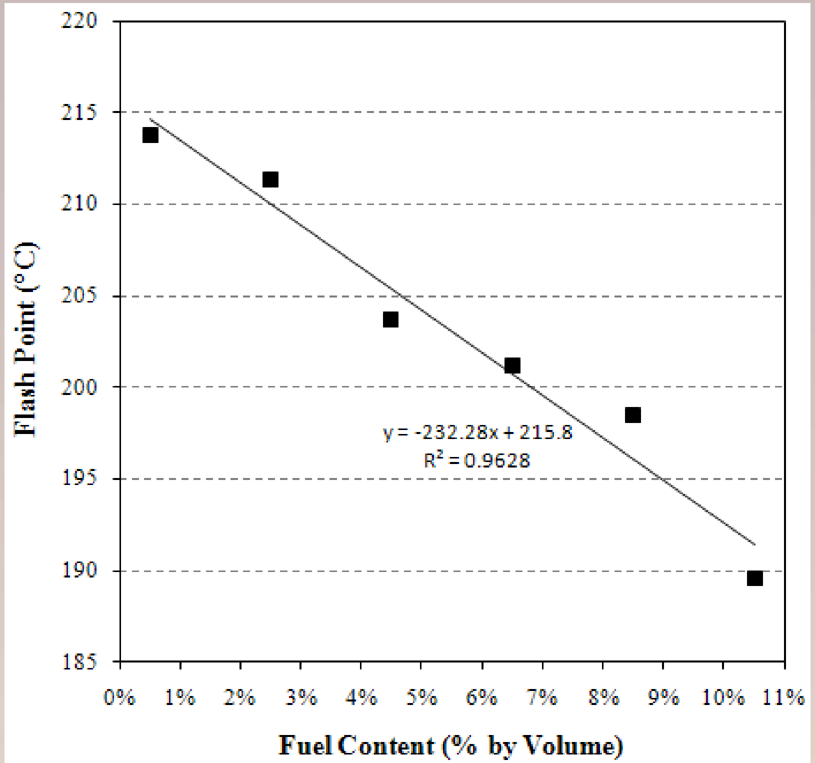




- Strong dependence of dielectric constant trends on the lubricant additive package.

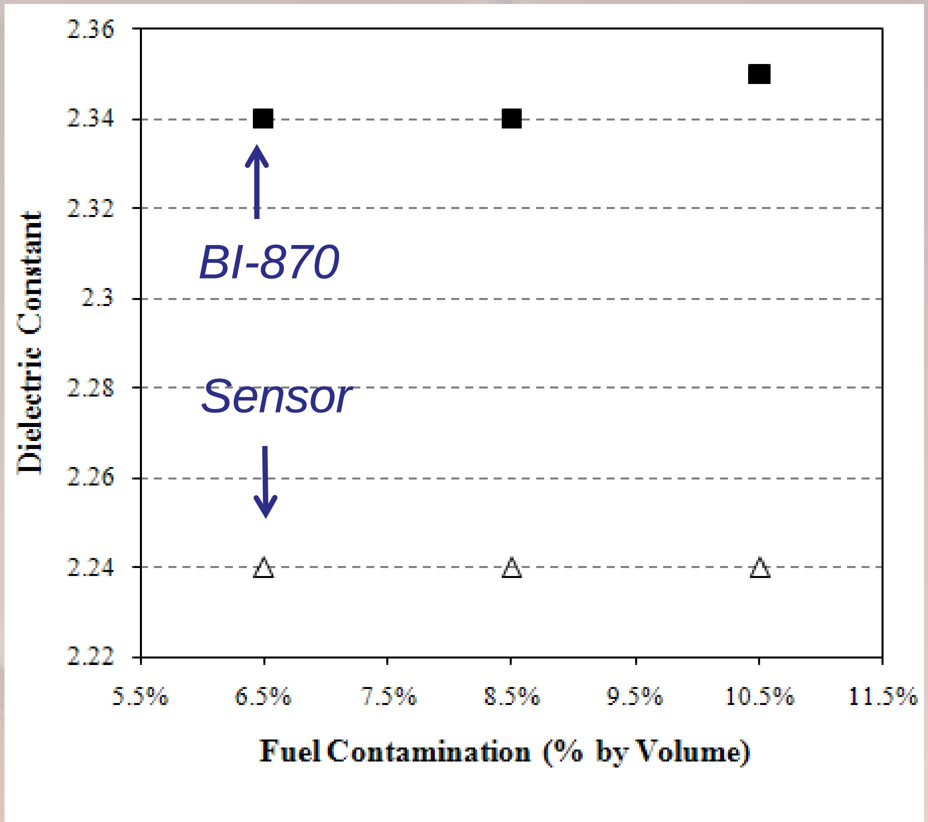
Results: Fuel-Contaminated Oil (1)

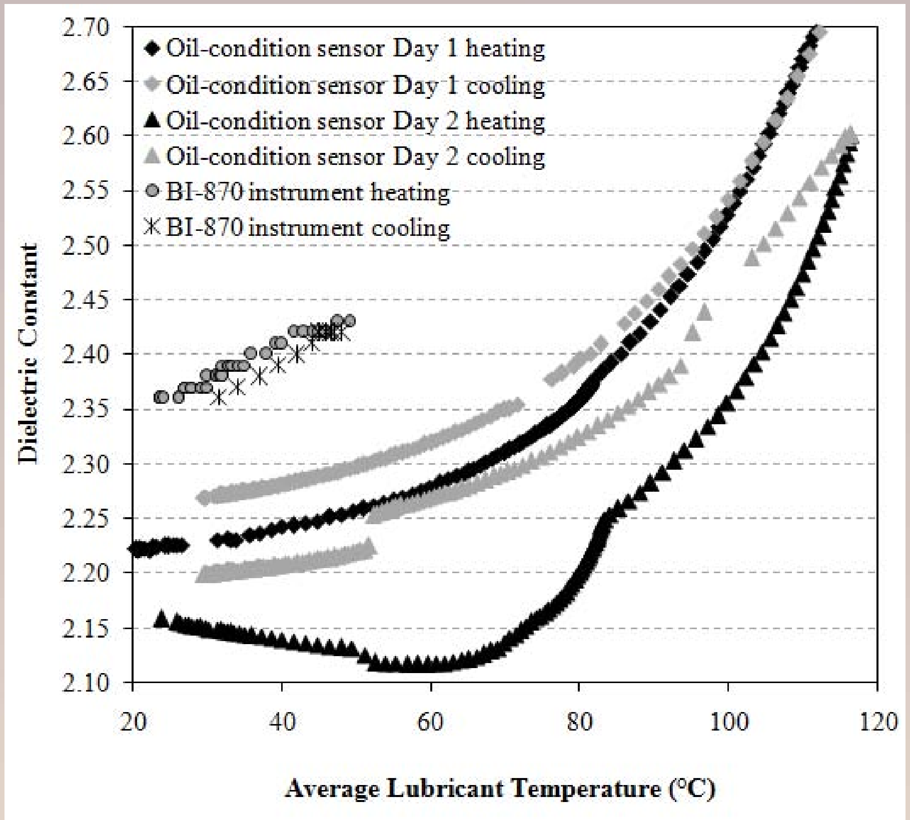




- Condemning limit for kinematic viscosity (18%) was reached at fuel concentrations of 9.4% (ASTM) and 7.4% (sensor)
- The flash point (ASTM D 92) decreased by 11.8 % from the baseline measurement as fuel contamination increased from 0.5% to 10.5%

Results: Fuel Contaminated Oil (2)

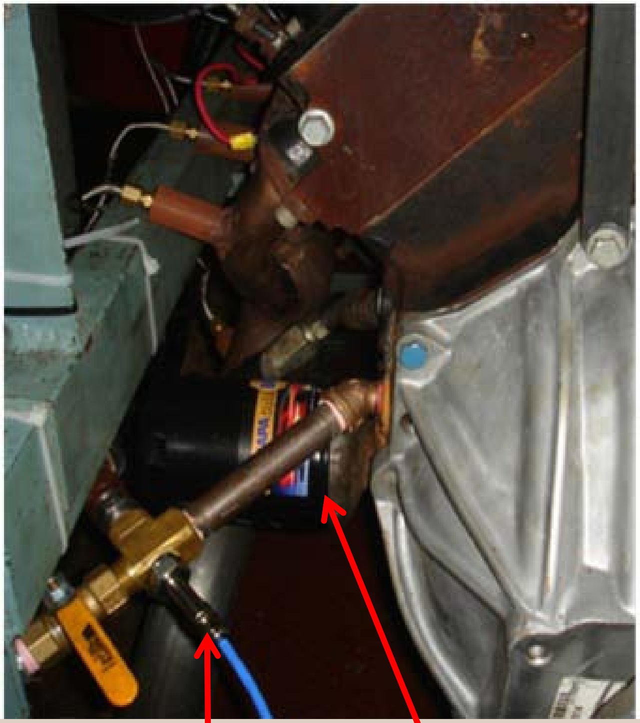




- Dielectric constant measurements are marginally insensitive to fuel contamination
- Dielectric constant trends measured during a thermal cycle are similar between non-contaminated and fuel-contaminated oil samples

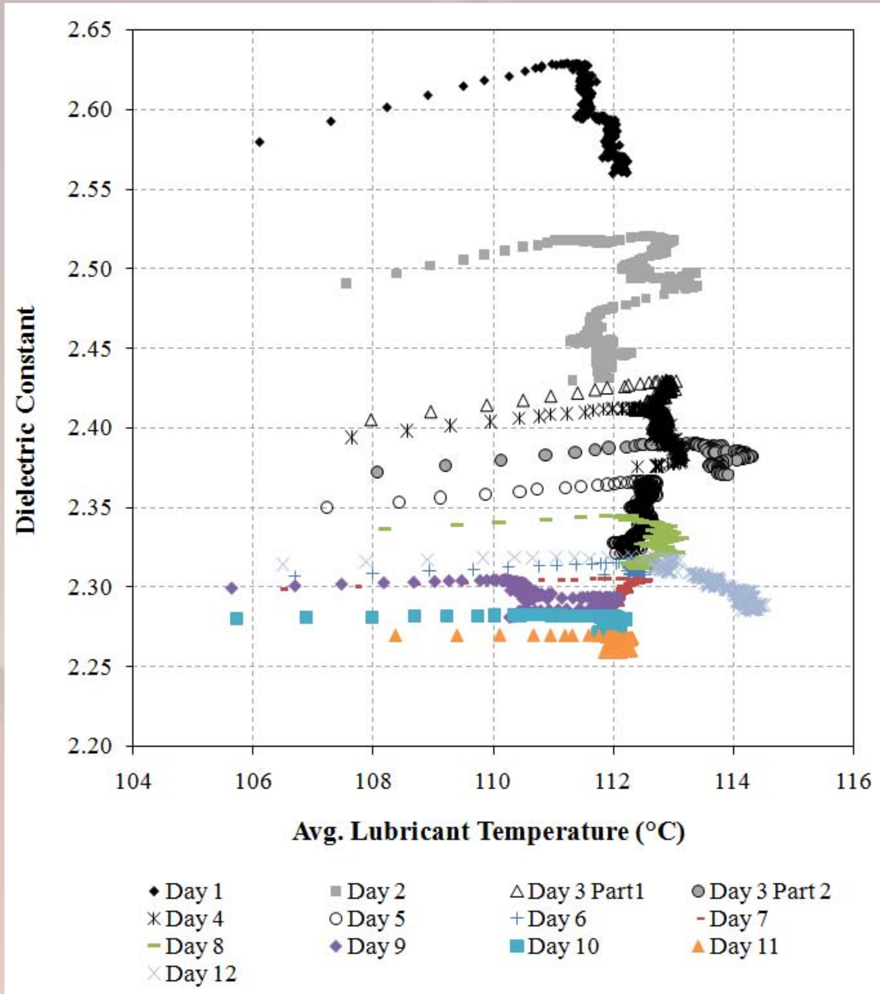
Engine Experiments: InitialTests

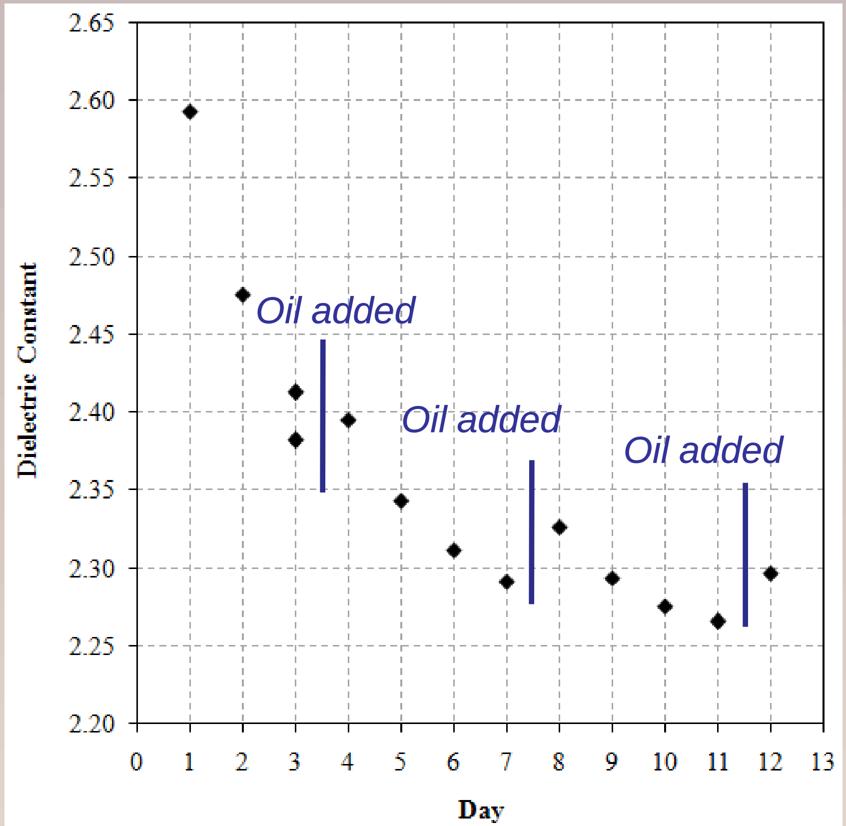
- Objective
  - Quantify changes in the physical properties of the lubricant as a function of engine operating time
- Experimental setup
  - Diesel engine
  - Sensor installed prior to oil filter
  - Operated for 73 hrs at 2,200 RPM and 75% maximum load
  - Oil sampled after the warm-up period and then approximately every 6 hrs. in 150mL increments



oil sensor *oil filter*

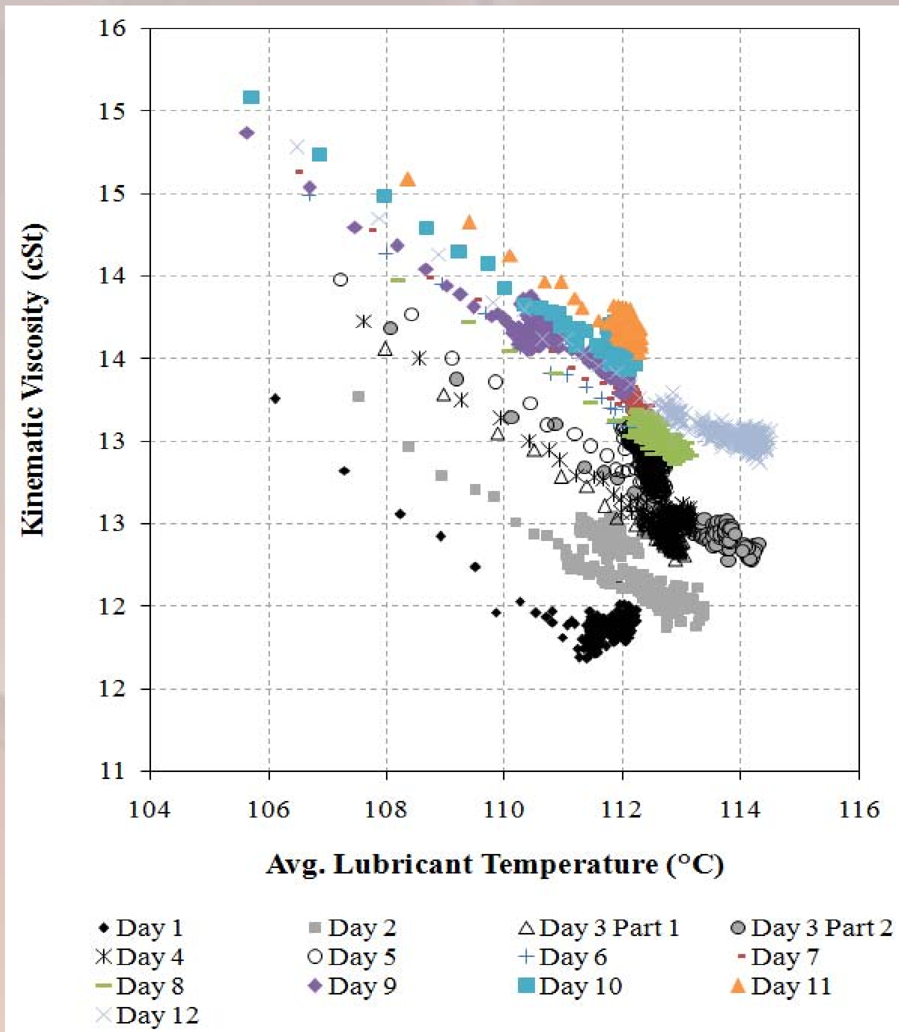
Results: Dielectric Constant

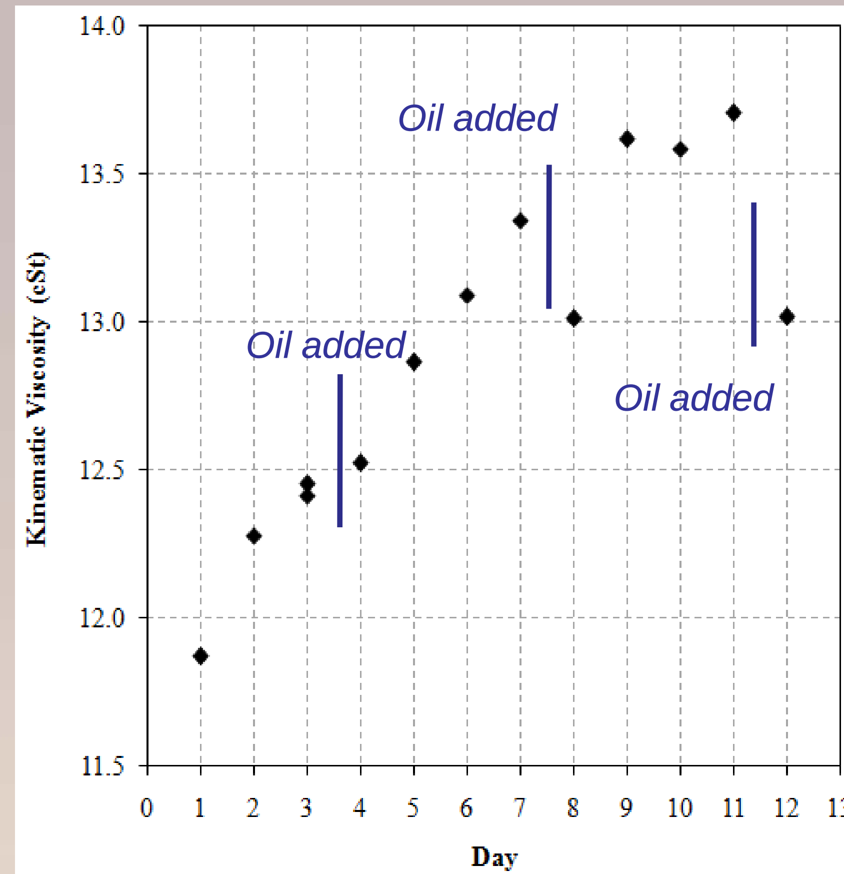




- Decrease of 11% over the course of engine tests
- Increase of 1.5% upon the addition of new oil

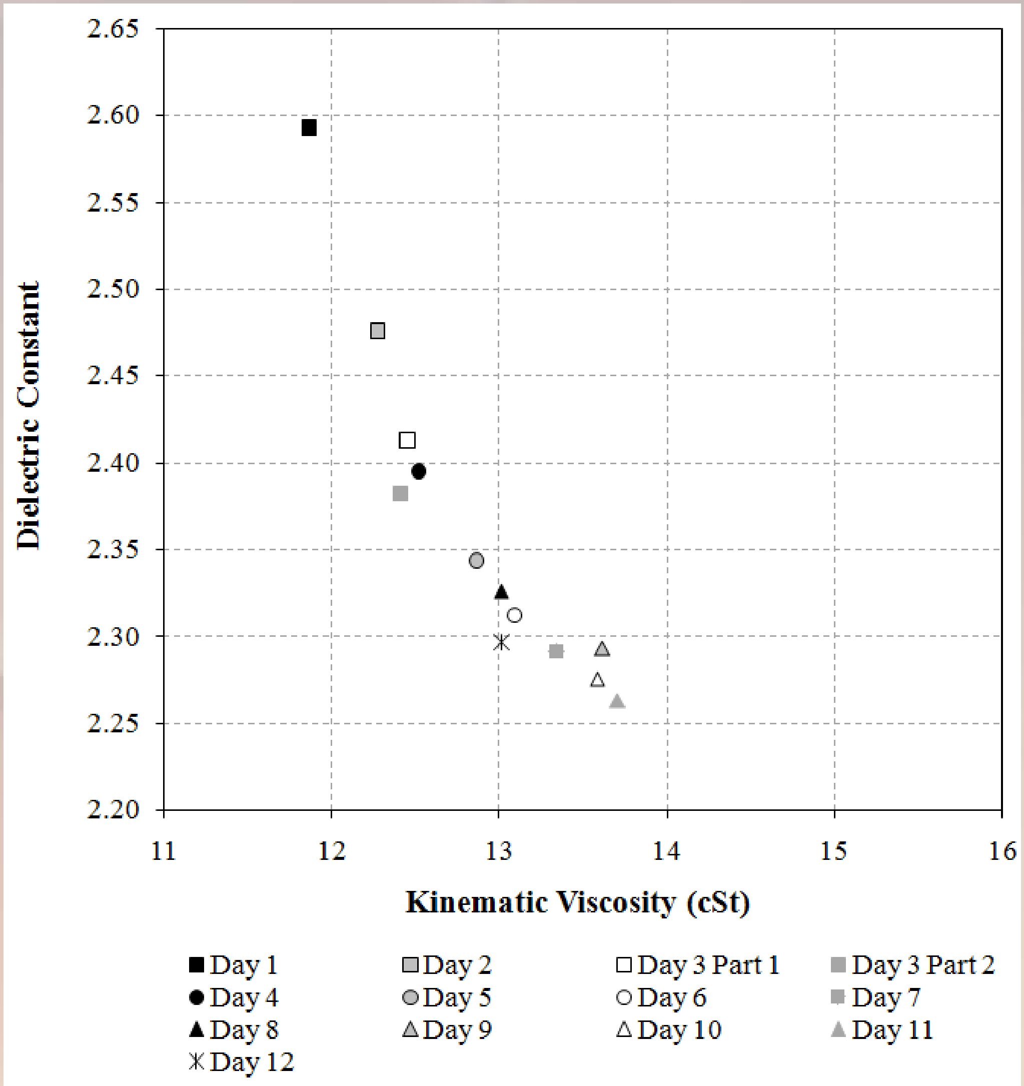
Results: Viscosity





- The viscosity increased by10% over the course of engine tests
- Detected increase of 4% upon the addition of new oil

Results: Property Trends



- The increase in dielectric constant might be attributed to additive depletion
- Increase in oxidation by-products causes a viscosity increase
- A simultaneous decrease in viscosity and increase in dielectric constant suggests the additive package depletion to have a dominant effect

Conclusions

- Baseline measurements
  - Kinematic viscosity
    - Sensor output and ASTM D445 agree within 6%
  - Dielectric constant
    - Sensor output and reference instrument agree within 6%
- Fuel-contaminated oil
  - Kinematic viscosity
    - As fuel contamination increases to 10.5%, the lubricant viscosity decreases by 21.5% (sensor) and 23.7% (ASTM)
  - Dielectric Constant
    - Marginal sensitivity to fuel contamination (0.5% to 10.5% by vol.)
- Engine experiments
  - Dielectric constant decreased 11%
  - Viscosity increased 10%
  - Correlation between dielectric constant and viscosity

Research Areas for Future Work

- Establish a dielectric constant threshold indicative of oil degradation
- Quantify correlations between thresholds in lubricant properties
  - Response surface methodology
- Quantify correlations in lubricant properties over longer periods of engine operation

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